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PATENT APPLICATION OF
KEVIN I. BERTNESS AND J. DAVID VONDERHAAR
ENTITLED
ELECTRONIC BATTERY TESTER/CHARGER WITH
INTEGRATED BATTERY CELL TEMPERATURE
MEASUREMENT DEVICE

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**ELECTRONIC BATTERY TESTER/CHARGER WITH
INTEGRATED BATTERY CELL TEMPERATURE
MEASUREMENT DEVICE**

BACKGROUND OF THE INVENTION

5 The present invention relates to storage batteries. More specifically, the present invention relates to a battery tester/charger with an integrated battery cell temperature sensing device.

10 Storage batteries, such as lead acid storage batteries, are used in a variety of applications such as automotive vehicles and stand by power sources. Typically storage batteries consist of a plurality of individual storage cells which are electrically connected in series. Each cell can have
15 a voltage potential of about 2.1 volts, for example. By connecting the cells in series, the voltages of individual cells are added in a cumulative manner. For example, in a typical automotive battery, six storage cells are used to provide a total voltage of
20 12.6 volts. The individual cells are held in a housing and the entire assembly is commonly referred to as the "battery".

 It is frequently desirable to ascertain the condition of a storage battery. Various testing
25 techniques have been developed over the long history of storage batteries. For example, one technique involves the use of a hygrometer in which the specific gravity of the acid mixture in the battery is measured. Electrical testing has also been used
30 to provide less invasive battery testing techniques.

A very simple electrical test is to simply measure the voltage across the battery. If the voltage is below a certain threshold, the battery is determined to be bad. Another technique for testing a battery is referred to as a load test. In the load test, the battery is discharged using a known load. As the battery is discharged, the voltage across the battery is monitored and used to determine the condition of the battery. More recently, a technique has been pioneered by Dr. Keith S. Champlin and Midtronics, Inc. of Willowbrook, Illinois for testing storage batteries by measuring a dynamic parameter of the battery such as the dynamic conductance of the battery. This technique is described in a number of United States patents and United States patent applications, for example U.S. Patent No. 3,873,911, issued March 25, 1975, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE; U.S. Patent No. 3,909,708, issued September 30, 1975, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE; U.S. Patent No. 4,816,768, issued March 28, 1989, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE; U.S. Patent No. 4,825,170, issued April 25, 1989, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE WITH AUTOMATIC VOLTAGE SCALING; U.S. Patent No. 4,881,038, issued November 14, 1989, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE WITH AUTOMATIC VOLTAGE SCALING TO DETERMINE DYNAMIC CONDUCTANCE; U.S. Patent No. 4,912,416, issued March 27, 1990, to Champlin, entitled

ELECTRONIC BATTERY TESTING DEVICE WITH STATE-OF-CHARGE
COMPENSATION; U.S. Patent No. 5,140,269, issued August
18, 1992, to Champlin, entitled ELECTRONIC TESTER FOR
ASSESSING BATTERY/CELL CAPACITY; U.S. Patent No.
5 5,343,380, issued August 30, 1994, entitled METHOD AND
APPARATUS FOR SUPPRESSING TIME VARYING SIGNALS IN
BATTERIES UNDERGOING CHARGING OR DISCHARGING; U.S.
Patent No. 5,572,136, issued November 5, 1996, entitled
ELECTRONIC BATTERY TESTER WITH AUTOMATIC COMPENSATION
10 FOR LOW STATE-OF-CHARGE; U.S. Patent No. 5,574,355,
issued November 12, 1996, entitled METHOD AND APPARATUS
FOR DETECTION AND CONTROL OF THERMAL RUNAWAY IN A
BATTERY UNDER CHARGE; U.S. Patent No. 5,585,416, issued
December 10, 1996, entitled APPARATUS AND METHOD FOR
15 STEP-CHARGING BATTERIES TO OPTIMIZE CHARGE ACCEPTANCE;
U.S. Patent No. 5,585,728, issued December 17, 1996,
entitled ELECTRONIC BATTERY TESTER WITH AUTOMATIC
COMPENSATION FOR LOW STATE-OF-CHARGE; U.S. Patent No.
5,589,757, issued December 31, 1996, entitled APPARATUS
20 AND METHOD FOR STEP-CHARGING BATTERIES TO OPTIMIZE
CHARGE ACCEPTANCE; U.S. Patent No. 5,592,093, issued
January 7, 1997, entitled ELECTRONIC BATTERY TESTING
DEVICE LOOSE TERMINAL CONNECTION DETECTION VIA A
COMPARISON CIRCUIT; U.S. Patent No. 5,598,098, issued
25 January 28, 1997, entitled ELECTRONIC BATTERY TESTER
WITH VERY HIGH NOISE IMMUNITY; U.S. Patent No.
5,656,920, issued August 12, 1997, entitled METHOD FOR
OPTIMIZING THE CHARGING LEAD-ACID BATTERIES AND AN
INTERACTIVE CHARGER; U.S. Patent No. 5,757,192, issued

May 26, 1998, entitled METHOD AND APPARATUS FOR
DETECTING A BAD CELL IN A STORAGE BATTERY; U.S. Patent
No. 5,821,756, issued October 13, 1998, entitled
ELECTRONIC BATTERY TESTER WITH TAILORED COMPENSATION
5 FOR LOW STATE-OF-CHARGE; U.S. Patent No. 5,831,435,
issued November 3, 1998, entitled BATTERY TESTER FOR
JIS STANDARD; U.S. Patent No. 5,914,605, issued June
22, 1999, entitled ELECTRONIC BATTERY TESTER; U.S.
Patent No. 5,945,829, issued August 31, 1999, entitled
10 MIDPOINT BATTERY MONITORING; U.S. Patent No. 6,002,238,
issued December 14, 1999, entitled METHOD AND APPARATUS
FOR MEASURING COMPLEX IMPEDANCE OF CELLS AND BATTERIES;
U.S. Patent No. 6,037,751, issued March 14, 2000,
entitled APPARATUS FOR CHARGING BATTERIES; U.S. Patent
15 No. 6,037,777, issued March 14, 2000, entitled METHOD
AND APPARATUS FOR DETERMINING BATTERY PROPERTIES FROM
COMPLEX IMPEDANCE/ADMITTANCE; U.S. Patent No.
6,051,976, issued April 18, 2000, entitled METHOD AND
APPARATUS FOR AUDITING A BATTERY TEST; U.S. Patent No.
20 6,081,098, issued June 27, 2000, entitled METHOD AND
APPARATUS FOR CHARGING A BATTERY; U.S. Patent No.
6,091,245, issued July 18, 2000, entitled METHOD AND
APPARATUS FOR AUDITING A BATTERY TEST; U.S. Patent No.
6,104,167, issued August 15, 2000, entitled METHOD AND
25 APPARATUS FOR CHARGING A BATTERY; U.S. Patent No.
6,137,269, issued October 24, 2000, entitled METHOD AND
APPARATUS FOR ELECTRONICALLY EVALUATING THE INTERNAL
TEMPERATURE OF AN ELECTROCHEMICAL CELL OR BATTERY; U.S.
Patent No. 6,163,156, issued December 19, 2000,

entitled ELECTRICAL CONNECTION FOR ELECTRONIC BATTERY
TESTER; U.S. Patent No. 6,172,483, issued January 9,
2001, entitled METHOD AND APPARATUS FOR MEASURING
COMPLEX IMPEDANCE OF CELL AND BATTERIES; U.S. Patent
5 No. 6,172,505, issued January 9, 2001, entitled
ELECTRONIC BATTERY TESTER; U.S. Patent No. 6,222,369,
issued April 24, 2001, entitled METHOD AND APPARATUS
FOR DETERMINING BATTERY PROPERTIES FROM COMPLEX
IMPEDANCE/ADMITTANCE; U.S. Patent No. 6,225,808, issued
10 May 1, 2001, entitled TEST COUNTER FOR ELECTRONIC
BATTERY TESTER; U.S. Patent No. 6,249,124, issued June
19, 2001, entitled ELECTRONIC BATTERY TESTER WITH
INTERNAL BATTERY; U.S. Patent No. 6,259,254, issued
July 10, 2001, entitled APPARATUS AND METHOD FOR
15 CARRYING OUT DIAGNOSTIC TESTS ON BATTERIES AND FOR
RAPIDLY CHARGING BATTERIES; U.S. Patent No. 6,262,563,
issued July 17, 2001, entitled METHOD AND APPARATUS FOR
MEASURING COMPLEX ADMITTANCE OF CELLS AND BATTERIES;
U.S. Patent No. 6,294,896, issued September 25, 2001;
20 entitled METHOD AND APPARATUS FOR MEASURING COMPLEX
SELF-IMMITANCE OF A GENERAL ELECTRICAL ELEMENT; U.S.
Patent No. 6,294,897, issued September 25, 2001,
entitled METHOD AND APPARATUS FOR ELECTRONICALLY
EVALUATING THE INTERNAL TEMPERATURE OF AN
25 ELECTROCHEMICAL CELL OR BATTERY; U.S. Patent No.
6,304,087, issued October 16, 2001, entitled APPARATUS
FOR CALIBRATING ELECTRONIC BATTERY TESTER; U.S. Patent
No. 6,310,481, issued October 30, 2001, entitled
ELECTRONIC BATTERY TESTER; U.S. Patent No. 6,313,607,

issued November 6, 2001, entitled METHOD AND APPARATUS
FOR EVALUATING STORED CHARGE IN AN ELECTROCHEMICAL CELL
OR BATTERY; U.S. Patent No. 6,313,608, issued November
6, 2001, entitled METHOD AND APPARATUS FOR CHARGING A
5 BATTERY; U.S. Patent No. 6,316,914, issued November 13,
2001, entitled TESTING PARALLEL STRINGS OF STORAGE
BATTERIES; U.S. Patent No. 6,323,650, issued November
27, 2001, entitled ELECTRONIC BATTERY TESTER; U.S.
Patent No. 6,329,793, issued December 11, 2001,
10 entitled METHOD AND APPARATUS FOR CHARGING A BATTERY;
U.S. Patent No. 6,331,762, issued December 18, 2001,
entitled ENERGY MANAGEMENT SYSTEM FOR AUTOMOTIVE
VEHICLE; U.S. Patent No. 6,332,113, issued December 18,
2001, entitled ELECTRONIC BATTERY TESTER; U.S. Patent
15 No. 6,351,102, issued February 26, 2002, entitled
AUTOMOTIVE BATTERY CHARGING SYSTEM TESTER; U.S. Patent
No. 6,359,441, issued March 19, 2002, entitled
ELECTRONIC BATTERY TESTER; U.S. Patent No. 6,363,303,
issued March 26, 2002, entitled ALTERNATOR DIAGNOSTIC
20 SYSTEM, U.S. Patent No. 6,392,414, issued May 21, 2002,
entitled ELECTRONIC BATTERY TESTER; U.S. Patent No.
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INTERFERENCE IN AC MEASUREMENTS OF CELLS, BATTERIES AND
OTHER ELECTRICAL ELEMENTS; U.S. Patent No. 6,424,158,
25 issued July 23, 2002, entitled APPARATUS AND METHOD FOR
CARRYING OUT DIAGNOSTIC TESTS ON BATTERIES AND FOR
RAPIDLY CHARGING BATTERIES; U.S. Patent No. 6,441,585,
issued August 17, 2002, entitled APPARATUS AND METHOD
FOR TESTING RECHARGEABLE ENERGY STORAGE BATTERIES; U.S.

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entitled VEHICLE ELECTRICAL SYSTEM TESTER WITH ENCODED
OUTPUT; U.S. Patent No. 6,456,045, issued September 24,
2002, entitled INTEGRATED CONDUCTANCE AND LOAD TEST
5 BASED ELECTRONIC BATTERY TESTER; U.S. Serial No.
09/703,270, filed October 31, 2000, entitled ELECTRONIC
BATTERY TESTER; U.S. Serial No. 09/780,146, filed
February 9, 2001, entitled STORAGE BATTERY WITH
INTEGRAL BATTERY TESTER; U.S. Serial No. 09/816,768,
10 filed March 23, 2001, entitled MODULAR BATTERY TESTER;
U.S. Serial No. 09/756,638, filed January 8, 2001,
entitled METHOD AND APPARATUS FOR DETERMINING BATTERY
PROPERTIES FROM COMPLEX IMPEDANCE/ADMITTANCE; U.S.
Serial No. 09/862,783, filed May 21, 2001, entitled
15 METHOD AND APPARATUS FOR TESTING CELLS AND BATTERIES
EMBEDDED IN SERIES/PARALLEL SYSTEMS; U.S. Serial No.
09/483,623, filed January 13, 2000, entitled ALTERNATOR
TESTER; U.S. Serial No. 09/960,117, filed September 20,
2001, entitled IN-VEHICLE BATTERY MONITOR; U.S. Serial
20 No. 09/908,389, filed July 18, 2001, entitled BATTERY
CLAMP WITH INTEGRATED CIRCUIT SENSOR; U.S. Serial No.
09/908,278, filed July 18, 2001, entitled BATTERY CLAMP
WITH EMBEDDED ENVIRONMENT SENSOR; U.S. Serial No.
09/880,473, filed June 13, 2001; entitled BATTERY TEST
25 MODULE; U.S. Serial No. 09/940,684, filed August 27,
2001, entitled METHOD AND APPARATUS FOR EVALUATING
STORED CHARGE IN AN ELECTROCHEMICAL CELL OR BATTERY;
U.S. Serial No. 09/977,049, filed October 12, 2001,
entitled PROGRAMMABLE CURRENT EXCITER FOR MEASURING AC

IMMITTANCE OF CELLS AND BATTERIES; U.S. Serial No. 60/330,441, filed October 17, 2001, entitled ELECTRONIC BATTERY TESTER WITH RELATIVE TEST OUTPUT; U.S. Serial No. 60/348,479, filed October 29, 2001, entitled
5 CONCEPT FOR TESTING HIGH POWER VRLA BATTERIES; U.S. Serial No. 10/046,659, filed October 29, 2001, entitled ENERGY MANAGEMENT SYSTEM FOR AUTOMOTIVE VEHICLE; U.S. Serial No. 09/993,468, filed November 14, 2001, entitled KELVIN CONNECTOR FOR A BATTERY POST; U.S.
10 Serial No. 09/992,350, filed November 26, 2001, entitled ELECTRONIC BATTERY TESTER, U.S. Serial No. 60/341,902, filed December 19, 2001, entitled BATTERY TESTER MODULE; U.S. Serial No. 10/042,451, filed January 8, 2002, entitled BATTERY CHARGE CONTROL
15 DEVICE, U.S. Serial No. 10/073,378, filed February 8, 2002, entitled METHOD AND APPARATUS USING A CIRCUIT MODEL TO EVALUATE CELL/BATTERY PARAMETERS; U.S. Serial No. 10/093,853, filed March 7, 2002, entitled ELECTRONIC BATTERY TESTER WITH NETWORK COMMUNICATION;
20 U.S. Serial No. 60/364,656, filed March 14, 2002, entitled ELECTRONIC BATTERY TESTER WITH LOW TEMPERATURE RATING DETERMINATION; U.S. Serial No. 10/098,741, filed March 14, 2002, entitled METHOD AND APPARATUS FOR AUDITING A BATTERY TEST; U.S. Serial No. 10/101,543,
25 filed March 19, 2002, entitled ELECTRONIC BATTERY TESTER; U.S. Serial No. 10/112,114, filed March 28, 2002; U.S. Serial No. 10/109,734, filed March 28, 2002; U.S. Serial No. 10/112,105, filed March 28, 2002, entitled CHARGE CONTROL SYSTEM FOR A VEHICLE BATTERY;

U.S. Serial No. 10/112,998, filed March 29, 2002,
entitled BATTERY TESTER WITH BATTERY REPLACEMENT
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5 AND BATTERIES EMBEDDED IN SERIES/PARALLEL SYSTEMS; U.S.
Serial No. 10/128,790, filed April 22, 2002, entitled
METHOD OF DISTRIBUTING JUMP-START BOOSTER PACKS; U.S.
Serial No. 60/379,281, filed May 8, 2002, entitled
METHOD FOR DETERMINING BATTERY STATE OF CHARGE; U.S.
10 Serial No. 10/143,307, filed May 10, 2002, entitled
ELECTRONIC BATTERY TESTER; U.S. Serial No. 60/387,046,
filed June 7, 2002, entitled METHOD AND APPARATUS FOR
INCREASING THE LIFE OF A STORAGE BATTERY; U.S. Serial
No. 10/177,635, filed June 21, 2002, entitled BATTERY
15 CHARGER WITH BOOSTER PACK; U.S. Serial No. 10/207,495,
filed July 29, 2002, entitled KELVIN CLAMP FOR
ELECTRICALLY COUPLING TO A BATTERY CONTACT; U.S. Serial
No. 10/200,041, filed July 19, 2002, entitled
AUTOMOTIVE VEHICLE ELECTRICAL SYSTEM DIAGNOSTIC DEVICE;
20 U.S. Serial No. 10/217,913, filed August 13, 2002,
entitled, BATTERY TEST MODULE; U.S. Serial No.
60/408,542, filed September 5, 2002, entitled BATTERY
TEST OUTPUTS ADJUSTED BASED UPON TEMPERATURE; U.S.
Serial No. 10/_____, (C382.12-0124), filed
25 September 18, 2002, entitled BATTERY TESTER UPGRADE
USING SOFTWARE KEY; U.S. Serial No. 60/_____,
(C382.12-0137), filed October 2, 2002, entitled QUERY
BASED ELECTRONIC BATTERY TESTER; and U.S. Serial No.
10/_____, (C382.12-0101), filed October 2, 2002,

entitled ELECTRONIC BATTERY TESTER WITH RELATIVE TEST OUTPUT, which are incorporated herein in their entirety.

In general, most prior art battery testing/charging techniques have utilized either the battery's ambient temperature or its external case temperature for applying temperature corrections to measured test results and/or for controlling charging of the battery. However, the causes of, and problems resulting from, localized internal heating of the battery, which can hinder proper charging and/or testing of the battery, are not addressed in such prior art battery testing/charging techniques.

SUMMARY OF THE INVENTION

An electronic battery tester for testing a storage battery that includes a battery housing with a plurality of electrochemical cells electrically connected to terminals of the battery is provided. The battery tester includes positive and negative connectors that can connect to the battery terminals. The tester also includes a temperature sensor that can measure a temperature of an individual electrochemical cell of the plurality of electrochemical cells. Processing circuitry, which is coupled to the temperature sensor, is configured to test the battery using the positive and negative connectors and to provide an output related to the temperature measured by the temperature sensor.

Another aspect of the invention includes a battery charger with an integrated battery cell temperature sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

5 FIG. 1 is a side cross-sectional view of a storage battery which can be tested/charged using a battery tester/charger of the present invention.

 FIG. 2-1 is a simplified block diagram of a battery charger/tester with an integrated battery
10 cell temperature sensor in accordance with an embodiment of the present invention.

 FIG. 2-2 is a plot showing an example battery cell-temperature curve for a 6-cell battery.

 FIG. 3 is a simplified block diagram of a
15 battery tester with an integrated battery cell temperature sensor in accordance with an embodiment of the present invention.

 FIG. 4 is a simplified block diagram of a battery charger with an integrated battery cell
20 temperature sensor in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

 The present invention provides a battery
tester/charger with an integrated temperature sensor
25 that is capable of measuring battery cell temperature. The tester/charger is configured to test/charge the battery and to provide an output related to the temperature measured by the temperature sensor.

FIG. 1 is a side cross-sectional view of a storage battery 10 which can be tested/charged using a battery tester/charger of the present invention. As illustrated in FIG. 1, battery 10 is a storage battery such as a lead-acid battery and includes a number of electrochemical cells in a battery housing 18 which are electrically connected in series by conductors 32. This forms a string of cells 30 having one end electrically coupled to a positive terminal 12 through conductor 34 and having the other end electrically coupled to a negative terminal 14 through conductor 36. Each cell 30 includes chemically active positive and negative plates that are insulated from each other by suitable separators and are submerged in an electrolyte. Chemical reactions between the electrolyte and the plates result in the production of electricity. In lead-acid battery cells, charged negative plates contain spongy (porous) lead (Pb) and charged positive plates contain lead peroxide (PbO_2). These substances are known as active materials of the plates. During the life of the battery, flakes of active material that drop off the plates of a cell can accumulate at the bottom of the case of a cell and cause a short circuit between the plates. Also, electrical connections 32 between two adjacent cells may deteriorate causing an open circuit condition between two cells. Such short circuit conditions within a cell, open circuit conditions between adjacent cells and other aberrations such as depletion of the electrolyte can result in

localized (restricted to a cell or a pair of adjacent cells) temperature changes within the battery. Therefore, obtaining individual battery cell temperature measurements and comparing these quantities with a nominal battery cell temperature (a temperature of a chosen pilot cell of the different battery cells (such as 30), for example) is desirable during battery testing/charging for providing a tester/charger user additional information on the condition of the battery.

FIG. 2-1 is a simplified block diagram of a battery charger/tester 40 with an integrated battery cell temperature sensor in accordance with an embodiment of the present invention. Circuitry of charger/tester 40 couples to terminals 12 and 14 of battery 10 through positive connector 16 and negative connector 17. Battery charger/tester 40 includes temperature sensor 42, a microprocessor or processing circuitry 44, a memory 46 and an output 48. Temperature sensor 42, which is capable of measuring battery cell temperature is coupled to microprocessor 44 and provides the battery cell temperature measurements to microprocessor 44. Microprocessor 44 is also coupled to memory 46 and output 48. In various aspects of the present invention, measured battery cell temperature is displayed to the tester/charger user via output 48, used to detect open circuit conditions within battery 10 and/or used to detect short circuit conditions within battery 10. Details regarding detecting open

circuit conditions and/or short circuit conditions within battery 10 are provided further below.

In some embodiments of the present invention, the temperature sensor is a non-contact
5 sensor which is capable of measuring the temperature of a particular cell when positioned proximate the particular cell of cells 30 as shown in FIG. 2-1. One example of a non-contact sensor which is suitable for use with the present invention is an infrared (IR)
10 temperature sensor. Cell temperature measurements are carried out by positioning the IR sensor proximate a side 20, 22 of battery 10 and aiming or directing a laser beam from the IR sensor at different points on the surface of battery housing 18 along side 20, 22 of
15 battery 10. At each different point, IR radiation that is emitted from the target (or point on the surface of battery 10) is focused onto an IR detector of the sensor, which determines the temperature of the target as a function of the radiation emitted from the target.

20 Examples of, and details regarding, IR temperature sensors suitable for use with the present invention are set forth in U.S. Patent No. 6,290,389, entitled "DEVICE FOR TEMPERATURE MEASUREMENT," U.S. Patent No. 6,234,669, entitled "DEVICE FOR MEASURING
25 TEMPERATURE WITHOUT CONTACT" and U.S. Patent No. 4,634,294, entitled "HAND-HELD DIGITAL TEMPERATURE MEASURING INSTRUMENT," which are incorporated herein by reference in their entirety.

In some embodiments of the present invention, temperature sensor 42 is a contact-type temperature sensor which is brought in contact with different points on the surface of battery housing 18
5 along side 20, 22 of battery 10. Temperature measurements are obtained by the contact-type sensor at each of these different points. Contact-type temperature sensors suitable for use with the present invention include thermistors, resistance temperature
10 detectors (RTDs), thermocouples and solid-state sensors. In embodiments of the present invention, these contact-type temperature sensors are protected with non-corrosive materials such as plastic, encapsulant, stainless steel, etc.

15 In general, any temperature sensor which provides accurate temperature measurements of small target areas without including unwanted background temperatures is suitable for use with battery charger/tester 40 of the present invention.

20 As mentioned above, temperature sensor 42 is coupled to microprocessor 44 using a suitable interface via which temperature measurements are provided to microprocessor 44. In some embodiments of the present invention, microprocessor 44 is configured to provide
25 the temperature measurements that it receives from sensor 42 to the tester user via output 48. In other embodiments, microprocessor 44 stores the temperature measurements in memory 46. These measurements are displayed on output 48 upon entry of a request by the

tester user via an input (such as 76, shown in FIG. 3), which is coupled to microprocessor 44.

FIG. 2-2 is an example battery cell-temperature curve 33 for a 6-cell battery, wherein each of the 6 cells (30-1 through 30-6) is a "good" cell (or cell having none of the above-mentioned aberrations). As can be seen in FIG. 2-2, the temperature of outer cells 30-1 and 30-6, which can relatively easily dissipate heat, is lower than the temperature of inner cells 30-2 through 30-5. As mentioned above, short circuit conditions within a cell, open circuit conditions between adjacent cells and other aberrations such as depletion of the electrolyte can result in localized (restricted to a cell or a pair of adjacent cells) temperature changes within the battery. These localized temperature changes are propagated to portions of battery housing 18 adjacent the cell(s). Thus, when temperature measurements of each cell of cells 30 are carried out in turn using temperature sensor 42, coupled to microprocessor 44, and substantial deviations or variations are present in the temperature readings, one or more of the above-mentioned conditions (aberrations) exist within battery 10. In embodiments of the present invention, microprocessor 44 is configured to carry out such comparisons between the different temperature measurements and accordingly indicate to the tester user, via output 48, the presence or absence of one or more such aberrations within battery 10.

In some embodiments of the present invention, microprocessor 44 compares each of the temperature measurements with one or more predetermined temperature thresholds, and based on these comparisons, indicates whether an open circuit condition, short circuit condition, etc., is present within battery 10. For example, if a certain cell temperature measurement is below a first threshold, microprocessor 44 reports, via output 48, that an open circuit condition is present within battery 10. Similarly, if a certain cell temperature measurement is above a second threshold, microprocessor 44 reports that a short circuit condition is present within battery 10.

It should be noted that the nominal temperature and the threshold temperature(s) can vary widely with ambient conditions. One way for obtaining the nominal temperature would be from a different temperature sensor already located proximate the battery. Here, the nominal temperature can be entered by the tester/charger user via input 72. Also, as mentioned above, a temperature of a chosen pilot cell of the different battery cells can be selected as the nominal temperature. Components of a battery tester with an integrated battery cell temperature sensor are described below in connection with FIG. 3.

FIG. 3 is a simplified block diagram showing components of a battery tester with an integrated battery cell temperature sensor in accordance with an embodiment of the present invention. In this

embodiment, instead of single connectors 16 and 17 (FIG. 2-1), a four point (or Kelvin connection) technique is used to couple battery tester 50 to battery 10. Kelvin connections 58 and 60 are used to couple to battery terminals 12 and 14, respectively, of battery 10. Kelvin connection 58 includes two individual connections 58A and 58B. Similarly, Kelvin connection 60 includes two individual connections, 60A and 60B.

10 Circuitry 50 includes a current source 62 and a differential amplifier 64. Current source 62 is coupled to connections 58B and 60B of Kelvin connections 58 and 60, respectively. Differential amplifier 64 is coupled to connection 58A and connection 60A of Kelvin connections 58 and 60, respectively. An output from differential amplifier 64 is provided to analog to digital converter 68 which itself provides a digitized output to microprocessor 44. Microprocessor 44 is connected to a system clock 72, a memory 46, and analog to digital converter 78. Microprocessor 44 is also capable of receiving an input from an input device 76 and providing an output to output device 48. The input can be, for example, a rating for the battery 10.

20 Input device 76 can comprise any or multiple types of input devices. The result of a battery test, either qualitative or quantitative, can be an output on device 48. As mentioned above, device 48 can be a display or other output. The invention can operate

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with any technique for determining a voltage across battery 10 and a current through battery 10 and is not limited to the specific techniques set forth herein. The forcing function source or current source 62 can provide any signal having a time varying component, including a stepped pulse or a periodic signal, having any shape, applied to battery 10. The current source can be an active source in which the current source signal is injected into battery 10, or can be a passive source, such as a load, which is switched on under the control of microprocessor 44.

In operation, microprocessor 44 can receive an input through input 76, such as a rating for battery 10. Microprocessor 44 determines a dynamic parameter, such as dynamic conductance, of battery 10 as a function of sensed voltage and current. The change in these sensed values is used to determine the dynamic parameter. For example, the dynamic conductance (ΔG) is determined as:

$$\Delta G = \Delta I / \Delta V \quad \text{EQ. 1}$$

where ΔI is the change in current flowing through battery 10 due to current source 62 and ΔV is the change in battery voltage due to applied current ΔI . Temperature sensor 42 can be thermally coupled to individual cells of battery 10 and operates in conjunction with microprocessor 44 as described above in connection with FIG. 3. Temperature readings can be stored in memory 46 for later retrieval.

In embodiments of the present invention, apparatus 50 is of a size suitable for portable use. Such a portable tester can include a moveable contact/non-contact temperature sensor with which
5 individual battery cell temperature measurements can easily be taken in turn.

FIG. 4 is a simplified block diagram of a battery charger with an integrated battery cell temperature sensor in accordance with an embodiment of
10 the present invention. Battery charger 80 includes charging circuitry 82, a microprocessor 44, a memory 46 and an output 48. Charger 80 couples to battery contacts 12 and 14 through connectors 16 and 17 respectively. Battery charger 80 operates in a manner
15 similar to the battery charger set forth in U.S. Patent No. 6,104,167, issued August 15, 2000, and entitled "METHOD AND APPARATUS FOR CHARGING A BATTERY", which is incorporated herein by reference. Further, temperature sensor 42, which is included in battery charger 80,
20 operates in conjunction with microprocessor 44 as described above in connection with FIG. 3.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that
25 changes may be made in form and detail without departing from the spirit and scope of the invention. In general, the invention is directed to a battery tester/charger with an integrated battery cell temperature sensor and is not restricted to the types

of chargers/testers with integrated cell temperature sensors described in the illustrative embodiments. Thus, any type of temperature sensor (contact or non-contact), known in the industry or developed in
5 future, which is capable of measuring battery cell temperature, can be employed, without departing from the scope and spirit of the present invention.